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USAARL REPORT NO. 84-11



**ANTHROPOMETRIC COCKPIT COMPATIBILITY ASSESSMENT
OF US ARMY AIRCRAFT FOR LARGE AND SMALL
PERSONNEL WEARING A COLD WEATHER, ARMORED VEST,
CHEMICAL DEFENSE PROTECTIVE CLOTHING CONFIGURATION**

AD-A145 472

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BIODYNAMICS RESEARCH DIVISION

July 1984

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER USAARL REPORT NO. 84-11	2. GOVT ACCESSION NO. AD-A145472	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Anthropometric Cockpit Compatibility Assessment of US Army Aircraft for Large and Small Personnel Wearing a Cold Weather, Armored Vest, Chemical Defense Protective Clothing Configuration		5. TYPE OF REPORT & PERIOD COVERED Final Report
7. AUTHOR(s) David O. Cote Aaron W. Schopper		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Biodynamics Research Division, SGRD-UAD US Army Aeromedical Research Laboratory Box 577, Fort Rucker, AL 36362		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Medical Research and Development Command Fort Detrick Frederick, MD 21701		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62777A 3E162777A879 BH 166
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE July 1984
		13. NUMBER OF PAGES 52
		15. SECURITY CLASS. (of this report) Unclassified
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Anthropometry, Aircraft, Cockpit-Compatibility, Chemical Defense, Cold Weather Clothing, Helicopters, Fixed-Wing Aircraft, Aerospace Medicine, Human Factors		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) See Back of Page		

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20. ABSTRACT

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~~This sequel to an earlier report~~ upon individuals wearing a warm weather uniform presents the results of an anthropometric cockpit compatibility evaluation conducted with individuals wearing a "worst-case" tactical clothing configuration; i.e., a combination of cold weather, armored vest, and chemical defense protective clothing. Subjects corresponding in stature to the uppermost and lowermost 5th percentiles of the Army male population were placed in the cockpits of all current US Army helicopters (except AAH-64) and fixed-wing aircraft, and requested to demonstrate critical operational reaches with the shoulder harness unlocked.

~~As in the previous report,~~ a relatively wide range of upper- and lower-body reach requirements were encountered. With the exception of a very large requirement associated with the TH-55 helicopter, upper-body reach requirements, as measured by total arm reach ("span"), ranged from 147-173 cm. For crotch height, the measure of leg-reach capability found most efficient, the range was 69-78 cm. Four aircraft could not accommodate the individual with the tallest sitting height (102 cm).

New and more extensive levels of previously encountered problems were evidenced regarding the ability of subjects to achieve full range of cyclic, stick, and yoke travel. Restraint harness and lap belt difficulties were also observed.

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PREFACE

This report is one of a series of reports on anthropometry in US Army Aviation produced by the US Army Aeromedical Research Laboratory (USAARL). Information on other reports in this series may be obtained by contacting the chief of the USAARL Scientific Information Center at AUTOVON 558-6907 or (205)255-6907.

Without the support of several personnel, this project would not have been possible. The authors would like to thank Headquarters, 1st Aviation Brigade, for its troop support coordination; the 46th Engineer Battalion, 1st Aviation Brigade, for providing a subject pool; the 46th Engineer Battalion personnel who volunteered their participation as subjects; Northrop Aviation Corporation, the Alabama Army National Guard, and the Alabama Army Reserve for providing aircraft; and the Aviation Logistics and Maintenance Division of the Directorate of Industrial Operations at Fort Rucker for providing hangar space.

Several people from USAARL aided in conducting this study. They include CPT George Mastroianni, who assisted in reducing the data, 2LT Robert McCaleb who reduced the data, SFC B.J. Clark, SSG David Wells, and SSG Max Bass who aided in data collection, Mr. Lynn Alford for building some of the anthropometric apparatus, and Mr. Larry Thomas who photographed, developed, and printed thousands of photographic prints.

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INTRODUCTION

Prior to 1980, no empirical basis existed for the anthropometric standards required for Class 1, 1A, and 2 flying duty. The anthropometric standards in Army Regulation (AR) 40-501 (Department of Defense 1960) used for aviator selection and retention were predicated solely upon descriptive anthropometric studies of male US Army personnel. Furthermore, the uppermost limit stated in this regulation was in conflict with the guidelines provided to aircraft designers and manufacturers. AR 40-501 cited a range for stature that corresponded to the 5th to 99th percentile male, whereas the guidance to the designers of aircraft cockpits, MIL-STD-1333A (Department of Defense 1976), utilized the 5th to 95th percentile male as a referent. Additionally, these guidelines had the effect of excluding a large percentage of the female population, since the 5th percentile male's stature corresponds (approximately) to the 50th percentile female's stature.

In response to requests for reevaluation from the Commanders of the US Army Aviation Center (ATZQ letter to The Surgeon General) and the Military Personnel Center (DAPC letter to The Surgeon General), The Surgeon General of the Army, through the US Army Medical Research and Development Command (DASG letter to USAMRDC, November 1979), tasked the US Army Aeromedical Research Laboratory (USAMRDC letter to USAARL, January 1980), to develop anthropometric criteria for medical fitness standards for entrance into, and retention in, the US Army Aviation Program.

An initial study performed by the second author (USAARL letter to USAMRDC, May 1980) resulted in the adoption of interim, revised minimum anthropometric criteria for reach-related dimensions. However, the study did not address maximum criteria, and it did not include all rotary-wing aircraft in the active US Army inventory. Furthermore, fixed-wing aircraft were not addressed nor were aircraft unique to the US Army National Guard or the US Army Reserve. To assure that these issues were evaluated, a comprehensive research program was undertaken subsequently to establish a complete set of minimum and maximum linear anthropometric criteria and strength criteria for all Army aircraft. A portion of that research effort reported earlier (Schopper and Cote, 1984) has described the results of the aircraft cockpit evaluations undertaken with personnel wearing only the equivalent of a warm-weather flight training uniform; i.e., one-piece flight suit, SPH-4 flight helmet, boots, aviator

gloves, and a survival vest. The present report describes the effort undertaken to determine the appropriate linear anthropometric requirements to assure an adequate aviator-to-cockpit fit for personnel wearing cold weather, survival vest with armor plate, and chemical defense protective clothing.

METHODS

MATERIALS

All aircraft in the Army inventory, to include those used exclusively by reserve and national guard components, were evaluated. Aircraft in the active Army inventory were the TH-55A, OH-58C, UH-1H, UH-60A, CH-47C, AH-1S, T-42A, U-21A, C-12A, and the OV-1D. Aircraft in Army Reserve and Army National Guard units were the OH-6A, the CH-54A, and the U-8F.

SUBJECTS

Eight hundred potential subjects initially were screened on the basis of stature to identify a subset of potential subjects with a reasonably uniform distribution of 1st to 5th and 95th to 99th percentile ranges for male upper and lower body reach capabilities. Candidate subjects so identified were subjected to further screening to attempt to obtain personnel in one centimeter increments from 182.9 cm to as tall an individual as could be identified. Short candidate subjects were screened further to identify those with statures below 162.7 cm, crotch heights between 69 cm and 75 cm, and a combined sitting height and functional arm reach of 150 cm to 156 cm. (See Glossary, Appendix A, for definition of anthropometric terms.) Once desired subjects were identified, they were asked to participate in the study. Some subjects who were willing to participate in the project were not allowed to due to conflicts with their unit's mission. Anthropometric screening profiles of the 18 subjects (13 males and 5 females) who participated in the study are listed in Table 1.

TABLE 1
ANTHROPOMETRIC SCREENING PROFILE
OF SHORT AND TALL SUBJECTS

STATURE	SITTING HEIGHT	FUNCTIONAL ARM REACH	SITTING HEIGHT AND FUNCTIONAL ARM REACH	CROTCH HEIGHT	SUBJECT NUMBER
SHORT SUBJECTS:					
146.9	80.5	71.8	152.3	68.7	4
152.5	80.0	67.4	147.4	73.7	2
153.4	83.8	68.1	151.9	71.0	1
155.9	86.4	68.0	154.4	72.4	3
156.4	83.6	72.0	155.6	72.3	7
158.3	83.9	79.3	163.2	76.2	8
161.1	87.2	76.1	163.3	77.6	6
162.5	90.8	72.3	163.1	75.4	5
TALL SUBJECTS:					
182.3	98.8	82.1	180.9	84.8	9
183.9	96.1	81.0	177.1	93.0	11
184.1	90.8	83.6	174.4	93.7	10
186.3	98.7	82.2	180.9	89.2	13
186.5	99.6	81.0	180.6	89.8	14
189.0	96.0	87.7	183.7	96.1	15
189.5	96.0	87.1	183.1	93.4	16
192.4	100.6	84.2	184.8	93.4	18
192.5	97.3	89.5	186.8	96.0	17
194.5	102.8	92.1	194.9	92.2	19

NOTE: Measurements are expressed in centimeters.

PROCEDURE

Anthropometric Measurements

After the 18 subjects were selected, they were brought to the laboratory for further measurements to aid in identifying the critical anthropometric dimensions for each aircraft. These measurements are listed in Table 2 and described in the Glossary, Appendix A. The actual measurements obtained for each of these dimensions are provided in Appendix B.

TABLE 2

ANTHROPOMETRIC MEASURES OBTAINED FROM SUBJECTS

<u>Body Dimension</u>	<u>Measurement Reference</u> *
Weight	1C
Stature	2C
Sitting Height	11C
Seated Eye Height	12C
Functional Arm Reach	2W
Biacromial Breadth	16T
Shoulder Breadth	23C
Crotch Height	7C
Buttock-to-Knee Length	17C
Buttock-to-Heel Length	191**
Functional Leg Length	22***
Seated Hip Breadth	29***
Foot Length	62C
Upper Body Reach	See Text
Total Arm Reach ("span")	797**
Forward Body Reach	See Text

* With the exceptions cited, all references are to the measures described in Churchill et al. (1977).

** Churchill et al. (1978)

*** Churchill et al. (1971).

One of two nonstandard measures included in the study was a proposed measure of upper body reach (UBR) capability. UBR was obtained from the individual seated on a chair with horizontal and vertical support surfaces at a right angle. A reference line was placed down the center of the two surfaces. The subject sat with the spinal column placed against the line on the vertical surface and the upper legs parallel to the

line on the horizontal surface. The buttocks, shoulder blades, and back of the head touched the rear, vertical surface. The right arm was extended horizontally, parallel to the floor and the thumb and index finger were pressed together as in the measure of functional arm reach (Churchill et al. 1977). The measurement was made from the point near the buttocks at which the vertical line on the back of the measurement chair intersected the forward/aft line on the seat of the chair, up and across the subject's back to the acromial notch of the right shoulder, along the upper surface of the arm to the end of the thumb. Figure 1 shows the UBR measure.

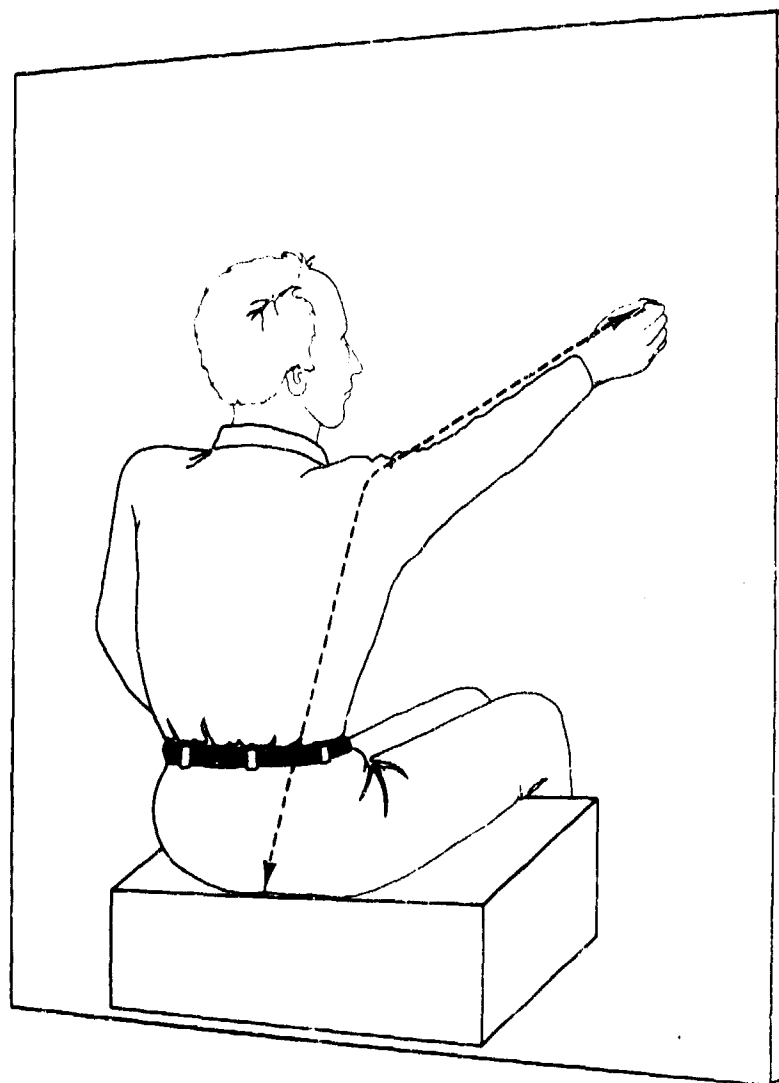


FIGURE 1. Upper Body Reach.

The second nonstandard measure addressed one's seated forward body reach capability. It was measured on a horizontal plane at a height 72.4 cm above the floor. The subject was seated 52.7 cm above the floor. Reaches were obtained separately for both arms in the forward direction in the midsaggital plane of the subject. The referent origin for these measurements corresponded to the point resulting from the intersection of the vertical back plane of the anthropometric measuring device, the cited horizontal plane, and the midsaggital plane of the normally-seated subject. The subject was instructed to bend at the waist and reach as far forward as possible while keeping the buttocks in firm contact with the seat and back of the anthropometric measurement device (Figure 2). A wooden dowel 15 cm high was placed within 2 cm of the front of the center of the crotch to ensure that the subject did not slide forward on the seat. A researcher also visibly inspected the subjects during their reaches to insure that they kept their buttocks in contact with the seat and the back of the device.



FIGURE 2. Forward Body Reach.

The measure of forward body reach was taken from the reference point on the seat back to the tip of their middle finger. The average of the left and right forward reaches is reported in Appendix B.

Critical Reaches

The assessment of subject-cockpit compatibility was based upon a set of critical reaches established by instructor pilots for each aircraft. These critical reaches included those for all three primary controls (i.e., the cyclic or yoke, collective, and pedals), and all ancillary controls (i.e., switches, dials, knobs, etc.) that instructor pilots judged to be critical to fly the aircraft in any conceivable flight situation, to include emergencies. Criteria then were established for each of the critical reaches. The critical reaches and their criteria are outlined in Table 3.

A complete listing of all critical ancillary controls is given in Appendix C. Subject-cockpit incompatibilities were recorded on data collection sheets.

Preparation of Aircraft

The preparation of an aircraft for data collection varied depending on the aircraft. Some aircraft had to have doors removed so that the subjects could be photographed in the cockpit, some had to have control linkages disconnected so the controls could be operated without the need for external power, and others had to have external power so the controls could be operated. No jacks or towing devices were allowed to stay on the aircraft when they were prepared for data collection or while data was being collected. Critical ancillary controls in the cockpit were identified with white tape.

The seat in each aircraft, when adjustable, was positioned to accommodate the short and tall subjects. For short subjects, the seat was raised as high as it would adjust in the vertical direction, and moved as far forward as it would adjust in the horizontal direction. When tall subjects were placed in the cockpit, the seat was lowered to its lowest vertical adjustment and moved as far back as it would adjust in the horizontal direction. For the one aircraft with a tilt adjustment, the CH-47C, the seat was tilted maximally upward and forward for the short subjects and maximally downward and rearward for the tall subjects. Table 4 contains the pilot seat adjustment capabilities for each aircraft.

TABLE 3
OPERATIONAL ASSESSMENT CRITERIA FOR PRIMARY CONTROLS
AND CRITICAL ANCILLARY CONTROLS

Controls	Criteria
cyclic	<ol style="list-style-type: none"> 1. Wrap right hand firmly around the cyclic in the full forward position such that full contact exists between the cyclic grip and the palm of the hand. 2. Move the cyclic to its full forward, aft, and lateral positions.
yoke	<ol style="list-style-type: none"> 1. Wrap both hands firmly around the yoke in the full forward and full aft positions so that full contact exists between the yoke handles and the palm of the hands. 2. Rotate the yoke to the full clockwise and counterclockwise positions.
collective	<ol style="list-style-type: none"> 1. Wrap left hand firmly around the collective in the full down position so that full contact exists between the throttle and the palm of the hand.
pedals*	<ol style="list-style-type: none"> 1. Place ball of right foot on the middle of the right pedal surface with the right pedal in the full forward position without sliding forward in the seat. 2. Place ball of left foot on the middle of the left pedal surface with the left pedal in the full forward position without sliding forward in the seat. 3. Place ball of right foot on the middle of the right pedal surface, ball of left foot on the middle of the left pedal surface, and boot heels resting comfortably on the heel pan or floor (depending on the aircraft) with the pedals at the center of their range of travel. 4. Maintain the balls of both feet on the centered pedals (as in 3 above) while simultaneously obtaining a firm grasp of the collective in its full down position (as described in "collective," above) and moving the cyclic through the range of motion.
Critical Ancillary Controls	<ol style="list-style-type: none"> 1. Reach and operate.

* Pedals were initially adjusted pairwise to either the extreme forward position (for tall subjects) or the extreme aft position (for short subjects) prior to assessing the reach capability of each subject.

TABLE 4
AIRCRAFT SEAT ADJUSTMENT CAPABILITIES

AIRCRAFT	ADJUSTMENT DIRECTION		
	Fore/Aft	Up/Down	Tilt
TH-55A *			
OH-6A *			
OH-58C *			
UH-1H	X	X	
UH-60A	X	X	
CH-47C	X	X	X
CH-54A	X	X	
AH-1S(pilot)		X	
AH-1S(copilot) *			
T-42A	X		
U-8F	X	X	
U-21G	X	X	
C-12A	X	X	
OV-1D		X	

*Seat does not adjust.

The pedals also were manually adjusted pairwise for the two groups of subjects. Pedals were adjusted to the full aft position for short subjects and to the full forward position for tall subjects.

Critical Reach Measurement

Critical reaches were attempted while wearing the one-piece flight suit and protective clothing. The protective clothing consisted of:

Extreme cold weather, F-1B aviator trousers (NSN 8415-00-269-0522)

Extreme cold weather, N-3B flight parka (NSN 8415-00-367-1710)

Extreme cold weather cotton duck boots (NSN 8430-00-269-0098)

Extreme cold weather boot insert/sock (NSN 8415-00-177-7992)

Chemical defense coat and trousers (NSN 8415-00-407-1060).

Survival vest, armor plated (NSN 8470-00-935-3192)

The armor-plated survival vest could have the armor inserted in the front and/or rear. Whether front, or front and rear armor plating was placed in the vest depended upon the helicopter. Some helicopters have armored seats, so wearing rear armor plate was not necessary. A fully-equipped, tropical survival vest (NSN 8465-00-1174-819) was worn in lieu of the armor-plated survival vest by personnel in fixed-wing aircraft since these aircraft do not fly missions which require the use of armor plating. Armor plating configurations worn for each helicopter are presented in Table 5.

TABLE 5

SURVIVAL VEST ARMOR-PLATE INSERT CONFIGURATIONS EMPLOYED

AIRCRAFT	Front Armor Plate	Front and Rear Armor Plate
TH-55A		X
OH-6A		X
OH-58C	X	
UH-1H	X	
UH-60A	X	
CH-47C		X
CH-54A		X
AH-1S (both seats)	X	

Subjects were placed in the pilot's seat of each aircraft as well as the copilot seat of the AH-1S. Then they were secured in the seat by fastening the shoulder harness and tightening the seat belt. In accordance with the operator's manual, the shoulder harness was left in the unlocked position; i.e., the subject could employ a "zone 3" reach (MIL-STD-1333A, Department of Defense 1976). Subsequently, they were instructed to: Move the cyclic to its full forward, full aft, full left, and full right positions; push the collective to its extreme downward position; push the left and right pedals to their extreme forward positions with the ball of the corresponding foot; and operate all critical ancillary controls (e.g., switches, knobs, reset buttons, etc.). In fixed-wing aircraft with yokes, subjects were instructed to move the yoke to the full forward and aft positions and rotate it to the extreme clockwise and counterclockwise positions.

Data Analysis

Success or failure to reach critical primary or ancillary controls was separately coded for each subject in each aircraft. These data then were used in conjunction with the anthropometric data available for each subject. Pass/fail information pertaining to critical hand-operated primary and ancillary controls was used in conjunction with separate rank-order listings of subjects for stature, functional arm reach, combined functional arm reach plus sitting height, upper body reach, average forward reach, total arm reach, and combined total arm reach plus sitting height. Similarly, pass/fail information pertaining to foot-operated controls was combined with separately generated rank-order listings of stature, functional leg length, buttock-to-heel length, and crotch height.

Once these pass/fail annotated, rank-ordered lists were generated for all aircraft, each was examined to determine a "critical value." The critical minimum value of a rank-ordered listing of subjects along a particular dimension for a specific aircraft was the value immediately above (i.e., larger than) the value at which a failure was observed. Ideally, all values smaller than the critical value would be those associated with subjects who were unable to perform the critical reaches. Likewise, all values equal to or larger than the critical value of an ideal dimension would correspond to those individuals who were able to perform the critical reaches. Unfortunately, the dimensions did not yield such an ideal circumstance. Misclassifications did occur; i.e., rank-order listings did result wherein there were values less than the "critical value" which corresponded to individuals who could, in fact, perform the critical reach satisfactorily.

In the interest of simplicity and parsimony, an analysis was undertaken to determine the "efficiency" of the various candidate measures associated with hand-operated controls and foot-operated controls. In the present context, "efficiency" was defined as that measure (or combination of measures) which yielded the fewest "misclassifications." Operationally, this determination entailed assembling the pass/fail-coded, rank-order listings of each measure for all aircraft and tabulating the total number of misclassifications associated with it. The most efficient measure was that which resulted in the fewest number of misclassifications.

RESULTS

The findings are summarized in Table 6. The values cited are those for the most efficient reach-related measure for hand-operated controls (total arm reach), for the most efficient measure of pedal reach (crotch height), and for the measure employed to evaluate head-to-roof compatibility (sitting height).

TABLE 6

SUMMARY OF CRITICAL ANTHROPOMETRIC MEASUREMENTS
REQUIRED IN US ARMY AIRCRAFT BY PERSONNEL
WEARING A COLD WEATHER, ARMORED VEST, CHEMICAL DEFENSE
PROTECTIVE CLOTHING CONFIGURATION

AIRCRAFT	MINIMUM TOTAL ARM REACH (cm)	MINIMUM CROTCH HEIGHT (cm)	MAXIMUM SITTING HEIGHT (cm)
ROTARY WING:			
TH-55 Trainer Helicopter	186	69*	96
OH-6A Observation Helicopter	164	71	99
OH-58C Observation Helicopter	165	76	95
UH-1H Utility Helicopter	159	75	102**
UH-60A Utility Helicopter	164	69*	102**
CH-47C Cargo Helicopter	169	69*	102**
CH-54A Cargo Helicopter	161	69*	102**
AH-1S Attack Helicopter	147*	76	102**
FIXED WING:			
T-42A	147*	71	95
U-8F	172	78	102**
U-21A	153	76	102**
C-12A	147*	74	102**
OV-1D	147*	75	102**

* No critical measurement observed, all subjects were able to attain the critical reach; the measurement cited is that of the subject with the shortest total arm reach or crotch height, as appropriate.

** No critical head-clearance problems were encountered; the value cited is that of the largest sitting height measured among the subjects participating in the study.

DISCUSSION

The findings are addressed by aircraft category, both helicopter and fixed-wing. Provided first are the results of the helicopter evaluations.

HELICOPTERS

The criteria used in evaluating rotary-wing aircraft depended upon whether or not they were crew-served aircraft. Crew-served aircraft must be flown with a rated aviator in both the pilot and copilot seats. Those considered as noncrew-served require only one rated aviator to be present (in the pilot's seat) during flight. For the latter category aircraft (i.e., the TH-55A, OH-6A, OH-58C, and UH-1H), all controls, switches, knobs, etc., designated as critical had to be operable by an individual sitting in the pilot's seat. For crew-served aircraft (i.e., the CH-47C, CH-54A, and UH-60A), the capabilities and operational responsibilities of both the pilots were considered vis-a-vis the need to reach critical primary and ancillary controls. Although the AH-1S is a crew-served helicopter, the seats are arranged in tandem. So, the critical controls for each position were treated independently as separate, single aviator crew stations during the evaluation of this aircraft.

The TH-55A training helicopter was evaluated for pilot-cockpit compatibility using the protective clothing configuration described. However, since this helicopter is not a tactical aircraft and is used only as an initial training aircraft, the problems observed during evaluation of tactical cold weather/chemical clothing may never be encountered.

All short personnel and some tall personnel (subjects 9 and 11) could not reach the altimeter. To set the altimeter while dressed in this clothing configuration required the pilot to have a total arm reach of at least 186 cm. Also, some subjects in both groups could not fasten the seat belt (subjects 8, 15, and 17). No tall subject, and only two short subjects (subjects 2 and 3) could input full lateral cyclic because the cyclic hit their legs before maximum lateral movement could be attained. A problem limited to short subjects, those with a total arm reach <163 cm, was not being able to firmly grasp the cyclic in the full forward position. Tall subjects whose sitting height exceeded 96 cm could not sit in a comfortable position due to insufficient head clearance in the TH-55A.

Short subjects encountered many reach-related problems in the OH-6A. Some could not reach the FM radio in the upper left corner of the instrument panel, some could not reach all critical points on the center console between the pilot and copilot seats, and some could not input full pedal.

The total arm reach necessary for operating all critical switches on the center pedestal and the FM radio was 164 cm. Those who could input full pedal had a crotch height of >71 cm.

Tall subjects in the the OH-6A had a problem with insufficient head clearance. Personnel with a sitting height >99 cm were forced to bend their upper torso forward while sitting in the OH-6A (Figure 3). Two tall subjects (17 and 19) had difficulty with the the cyclic hitting their legs before it reached the extreme lateral positions. Only if they rotated their hand and arm and placed their right hand on the left side of the cyclic grip were they able to input full right cyclic. This procedure would not be acceptable during actual flight.

In the OH-58C, short subjects wearing the prescribed combination of tactical clothing and protective equipment had a variety of reach problems. None of the short subjects could reach the UHF-AM radio on the copilot's side of the instrument panel, and some could not reach all critical points on the center console between the pilot and copilot seats. Therefore, additional, larger subjects were recruited and subjected to the same evaluation process as was employed for all previous subjects. The results of this evaluation indicated that a total arm reach of >165 cm is required. However, subjects with a total arm reach >164 cm were able to reach all of the center console between the seats and all of the instrument panel to the right of the vertical row of 6 gauges (i.e., fuel quantity, ammeter, torquemeter, etc.) on the copilot's side of the instrument panel. Thus, if an observer was present and capable of tuning the radios on the left side of the instrument panel, the pilot would need only a total arm reach of 164 cm.

None of the tall personnel experienced leg reach problems in the OH-58C; however, most small subjects did. Only those whose crotch height exceeded 76 cm could attain proper pedal input with the pedal in the full forward position. All short subjects (except subject 8) and tall subjects (11, 16, 17, and 19) found that they could not input full lateral cyclic due to cyclic contact with their legs. To input full cyclic, they had to move their feet from the pedals. This problem was not encountered by as many of the same group of subjects in the earlier reported evaluation

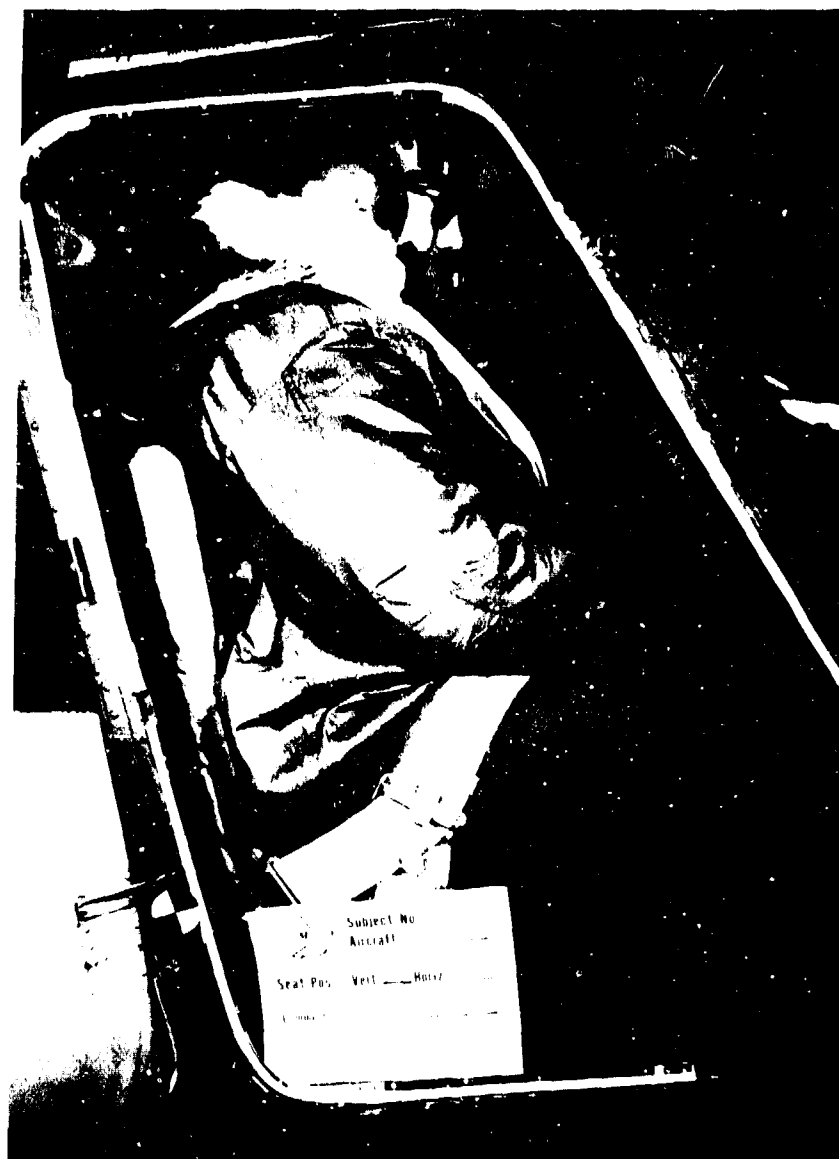


FIGURE 3. Tall Subject in an OH-58C; Helmet is in Contact With Roof of the Cockpit.

(Schopper and Cote, 1984) of the OH-58C in which they wore the one-piece flight suit without protective clothing. So, the additional bulk associated with the cold weather and chemical protective clothing appears to exacerbate this problem.

Some tall subjects in the OH-58C also found that they could not sit in a normal, comfortable position due to insufficient head clearance. Personnel with a sitting height

>96 cm had to lean forward and assume a posture which would contribute to fatigue of the muscles in the shoulder and neck.

In the UH-1H, only those personnel with a total arm reach >159 cm could reach all critical ancillary controls on the center console between the pilot and copilot seats and on the overhead console. However, all short subjects could reach all such controls on the pilot's side of both consoles. Thus, if a copilot was available in the left seat, the present data indicate that even the smallest subject employed in the study could attain all other reaches on the pilot's side of the aircraft.

Another problem encountered by short personnel in the UH-1H was the inability to input full pedal. Only those subjects with a crotch height >75 cm could input full pedal.

Another leg-related problem evidenced by members of both groups was that pertaining to lateral cyclic movement. Because the cyclic contacted their legs, one short subject (3) and three tall subjects (16, 17, and 19) were unable to achieve full lateral movement of this control. There were no head-clearance problems encountered.

Reach-related problems in the UH-60A were confined to short subjects. Short subjects with a total arm reach <164 cm could not reach the circuit breakers located at the left rear of the console between the seats, the ADF receiver at the upper left of this console, and the essential DC bus panel and light control panel located on the copilot's side of the overhead console. However, all these points easily could be reached by anyone in the copilot's seat.

There were no leg-reach or head-clearance problems noted for either short or tall subjects dressed in the protective clothing configuration. However, there were other problems encountered in the UH-60A pertaining to range-of-movement for the seat and problems relating to the size of the restraint system employed.

The full forward seat position in the UH-60A was not compatible with personnel wearing front armor plate. All short subjects had to move their seat to the full aft horizontal position to input full aft cyclic without having the cyclic hitting their front armor plate. Thus, the entire range of seat adjustment is not usable while wearing protective armor and clothing.

The pilot restraint system in the UH-60A also was not compatible with the wearing of protective clothing configurations employed in this study. All tall subjects and

one of the short subjects (8) could not fasten the lap belt because it was too short. Furthermore, for two tall subjects (14 and 16), the shoulder straps had to be fully extended before they could be fastened. This prevented the subjects from having any forward body movement although they were still able to perform all critical reaches.

In the CH-47C, none of the short subjects could reach all the critical points on the overhead console. Therefore, additional, larger personnel were recruited and evaluated as those previously had been. The results of this evaluation revealed that individuals whose total arm reach was >169 cm could functionally reach all critical switches and knobs on the overhead switch panel. Tall personnel had severe overhead reach problems with the seat in the full down position. However, placing the seat in the full up position eliminated these problems. No head-clearance or leg-reach problems were encountered by subjects in either group.

In the CH-47C, as in the UH-60A, cyclic clearance was a problem, particularly in the aft direction. Some short subjects had to move the seat aft 7 to 8 cm to obtain full aft cyclic. With the seat in the full forward position, the cyclic would hit the front armor plate before it reached the full aft position. One tall subject (17) could not input full aft cyclic even with the seat in full aft position. Also, this individual could not input full left or right cyclic without removing his feet from the pedals.

The problems found in the CH-54A were similar to those cited for the CH-47C and UH-60A. Overhead reaches were a problem for short subjects as were reaches to some critical instrument panel switches and reaches to critical center console controls. Short subjects whose total arm reach was a minimum of 161 cm were able to achieve these reaches.

No leg-reach or head-clearance problems were encountered in the CH-54A by subjects in either group. However, tall personnel could not employ the full aft seat position because the shoulder straps were pinched between the seat back and the seat. Short subjects also encountered a fore-aft seat adjustment problem because of the rearward travel of the cyclic. The seat had to be moved rearward to either the last or next-to-last adjustment to preclude contact between the armor plate and the cyclic in the rearmost position.

Both seats of the AH-1S were evaluated for possible subject-cockpit incompatibilities. In contrast to the other helicopters evaluated, there were no hand-operated control reach-related problems encountered in this aircraft. No head-clearance problems were found, either. However, there

were substantial leg-reach problems for small subjects and problems for large personnel in achieving full lateral cyclic input.

None of the short personnel could input full pedal with the seat in the full up position. However, with the seat moved down one notch, it was possible for personnel with a crotch height >76 cm to achieve the required pedal input while still retaining an adequate functional view of the aircraft's sighting reticle.

When placed in the front, copilot/gunner seat, short personnel with a crotch height <75 cm could not input full pedal. Both short and tall personnel could not lean forward enough to look into the copilot/gunner's sight while wearing the front armor plate (Figure 4). The armor plate was too long, choking them when they leaned forward. A redesign of the armor plate is needed to make this task accomplishable while wearing protective armor.

In the pilot's seat, some tall personnel (14, 17, and 19) could not input full lateral cyclic. When they tried to move their legs out of the way to input full lateral cyclic, their legs hit the sides of the cockpit.



FIGURE 4. Subject in the AH-1S Copilot/Gunner (Front) Seat.

FIXED-WING AIRCRAFT

The T-42A is a fixed-wing trainer aircraft and thus may never be flown by pilots wearing the cold weather and chemical protective clothing. As previously indicated, protective armor was not worn during the evaluation of any fixed-wing aircraft.

The only reach-related problem some short subjects had in the T-42A trainer aircraft was not being able to input full pedal. Those who could not input full pedal had a crotch height <71 cm. Tall personnel did not have any hand-related reach problems, but some did find that they could not sit in a comfortable position in the T-42A due to insufficient head clearance. While wearing a helmet, personnel with a sitting height >95 cm had to bend forward while sitting in the pilot's seat. Without the helmet, only subjects with a sitting height >98 cm had this problem.

Tall subjects in the U-8F did not experience any difficulties. However, short subjects encountered several reach problems. Short subjects with a crotch height <78 cm could not input full pedal and those with a total arm reach of >163 cm could not reach the oil shutoff switch or the emergency landing gear handle. Furthermore, none of the short personnel could reach the 750 volt inverter circuit breaker, the flap motor circuit breaker, or the landing gear circuit breaker. All these circuit breakers are on the copilot's side of the cockpit and would be readily accessible to anyone sitting in the copilot's seat. To reach these circuit breakers from the pilot's seat would require a total arm reach of 172 cm. Thus, if the pilot is unaccompanied by someone in the copilot seat, the critical reaches for the pilot would be a total arm reach >172 cm and a crotch height >78 cm.

In the U-21A, as in the U-8F, tall personnel did not encounter any problems and short subjects encountered several problems. The first problem short personnel had was not being able to fasten the lap belt with the seat in the full forward and full up position because the seat belt was too short. Short subjects could not input full pedal from this seat position, either. To allow short personnel to buckle the seat belts, the seat had to be lowered to the full down position and moved half way back. In this position, only those with a crotch height >78 cm could input full pedal. If the seat was moved further forward to determine whether subjects with crotch heights <78 cm could input full pedal, the seat belt could not be fastened because it was too short. However, by moving the seat fully forward and down one notch,

personnel with a crotch height ≥ 76 cm could achieve full pedal input.

Another problem encountered by short subjects in the U-21A was not being able to reach the flap motor circuit breaker on the copilot's side of the cockpit. Personnel with a total arm reach >153 cm could operate this circuit breaker. However, it is readily accessible to anyone in the copilot's seat.

Short personnel also had reach problems in the C-12A. Those with a crotch height <74 cm could not input full pedal and none of the short personnel could reach the emergency landing gear handle with the seat in the full up, full forward position. However, if it was necessary to grasp the emergency landing gear, they could reach it by lowering the seat and moving it aft. This procedure would be acceptable since this aircraft is dual piloted. If the situation were to arise that two of the smallest eligible individuals were to be flying the aircraft when the emergency landing gear handle had to be operated, the copilot would have to assume control of the aircraft while the individual sitting in the pilot position lowered his or her seat and moved it back as required to grasp the handle.

A unique problem was observed in the C-12A. Nearly all short personnel and some tall personnel (13, 15, 17, and 19) could not rotate the yoke to the full clockwise position without removing their right hand from the yoke. If they kept their right hand on the yoke, their hand would hit their leg, preventing full clockwise rotation. One tall subject (17) still had the yoke hit his leg when he removed his hand from the yoke. Pilots should be aware of this problem and determine what they would have to do to obtain full clockwise rotation of the yoke.

Short personnel in the OV-1D encountered difficulty inputting full pedal. Personnel with a crotch height <75 cm could not input full pedal. Short personnel with crotch heights less than this could input full pedal if the seat was lowered, but then their outside visibility was compromised. Some short subjects (1, 3, and 5) and tall subjects (10, 11, and 17) could not input full lateral control stick movement due to it hitting their legs. To obtain full lateral cyclic movement they had to remove their feet from the pedals.

A unique problem also was observed in the OV-1D. All subjects had sufficient upper limb reaches to operate all critical switches, dials, knobs, etc., but some short subjects did not have enough strength to pull themselves

sufficiently forward to make the reaches. The shoulder harness inertial reel required so much force to extend the shoulder harness that some subjects had to pull themselves forward by grasping the glare shield with their left hand in order to tune the radios on the instrument panel with their right hand.

SUMMARY

The historical 5th-99th percentile male anthropometric requirements associated with US Army Class 1, 1A, and 2 flight physicals have existed for some time without having been subjected to an empirical validation. To remedy this circumstance, a large-scale aircraft cockpit-compatibility study was initiated.

This report addresses the static evaluation undertaken to assess the anthropometric limits of individuals necessary to assure their compatibility with the cockpits of all US Army aircraft while wearing a "worst-case" tactical clothing configuration. Eight short subjects ranging in stature from 146.9 cm to 162.5 cm, and ten tall subjects ranging in stature from 182.3 cm to 194.5 cm were placed in the cockpits of each of the US Army's helicopters and fixed-wing aircraft to evaluate upper- and lower-body reach requirements and helmeted head-clearance requirements. The measures most successful in discriminating between those who did and those who did not experience upper- and lower-body reach difficulties were total arm reach ("span") and crotch height, respectively. Sitting height was employed to evaluate head clearance.

Among helicopters (with the exception of the TH-55A training helicopter), total arm reaches required to operate instructor-pilot designated critical controls, switches, etc., ranged from 147 cm for the AH-1S attack helicopter to 169 cm for the CH-47C cargo helicopter. The Army's training helicopter, TH-55A, required a total arm reach of 186 cm. All other helicopters required total arm reaches in the 159-165 cm range. With the exception of the U-8F at 172 cm, fixed-wing aircraft were much less demanding. All critical reaches in the remaining four fixed-wing aircraft (T-42A, U-21A, C-12A, and OV-1D) could be attained by individuals whose total arm reach was at least 153 cm.

With two exceptions, the leg-reach requirements for helicopters ranged from 69-76 cm in crotch height. The TH-55A, UH-60A, CH-47C, and CH-54C at 69 cm and the OH-6A at 71 cm posed the least demanding requirements. Intermediate in their demands were the UH-1H at 75 cm and the OH-58C and AH-1S at 76 cm. Fixed-wing aircraft leg-reach requirements ranged from 71 cm (T-42A) to 78 cm (U-8F and U-21A) in crotch height. The crotch height requirements of the intermediate C-12A and OV-1D were 74 and 75 cm, respectively.

Head clearance was a problem encountered in three helicopters and one fixed-wing aircraft. Sitting heights of 95-96 cm or less were required to enable a helmeted aviator to sit in the TH-55A, OH-58C, and T-42A without the helmet touching the overhead surface of the cockpit. A sitting height of 99 cm or less was required for the OH-6A. All other aircraft accommodated the individual in the study with the largest sitting height, 102 cm, without helmet contact.

The wearing of this "worst-case" combination of tactical clothing resulted in either the appearance of, or the exacerbation of, several other aviator-cockpit compatibility problems. Dressed in this protective clothing combination, tall personnel were unable to achieve appropriate full lateral cyclic input in the OH-6A, OH-58C, CH-47C, AH-1S (rear seat), and OV-1D. The same applied to short personnel in the OH-58C and the OV-1D. Similarly, in the C-12A full clockwise movement of the yoke was not possible for several of the short and tall individuals. Full aft travel of the cyclic was not possible for short subjects with the seat full forward in the UH-60A, CH-47C, and CH-54 because of cyclic contact with the armored vest. Shoulder harness straps were found to be too short for some large individuals in the TH-55 and UH-60A. Inertia reel force requirements prevented short personnel from being able to attain reaches that were otherwise within their capability in the OV-1D unless they simultaneously removed their hand from the stick, grasped the glare shield, and pulled themselves forward while making the requisite reach with the remaining hand. Lap belts were found to be too short in the TH-55, UH-60A, and U-21A.

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APPENDIX A
GLOSSARY

ACROMION: Highest point of the scapula.

ANTHROPOMETRY: The scientific study of the measurement of the human body.

*

BIACROMIAL BREADTH: Horizontal distance between the lateral edges of the acromial processes of the shoulder.

BUTTOCK-TO-HEEL LENGTH: Horizontal distance from the most posterior protrusion of the buttock to the bottom of the heel (measured with the subject seated, the leg extended in the same plane as the chair seat and the buttocks in contact with the back of the chair)

*

BUTTOCK-TO-KNEE LENGTH: Horizontal distance from the most posterior protrusion of the buttock to the most anterior point of the kneecap.

*

CROTCH HEIGHT: Vertical distance from floor to midpoint of crotch.

*

FOOT LENGTH: Length of foot (clothed in a wool sock) measured parallel to its long axis.

FORWARD BODY REACH: Measurement taken with the subject seated on an anthropometric measurement device. Chair seat and chair back intersect at a 90 degree angle. Subject leans forward at the waist, keeping the posterior portion of the buttock in contact with the seat back, and extends either arm on a surface above the chair seat. Reach measurement is the horizontal distance from the most posterior protrusion of the buttock to the tip of the middle finger with the subject reaching as far forward as possible.

*

FUNCTIONAL ARM REACH: Horizontal distance from a wall to the tip of the thumb. Measured with the subject's back against the wall, the right arm horizontal to the floor, and the tip of the index finger touching the pad of the thumb.

**

FUNCTIONAL LEG LENGTH: Measurement taken with subject sitting erect on the edge of a chair without any back support

and the right leg extended straight to a distance 5 cm above the floor. Functional leg length is the distance along the main axis of the leg from the bottom of the heel to the posterior waist landmark.

PATELLA: Knee cap

*

SEATED EYE HEIGHT: Vertical distance from sitting surface to the outer corner of the eye.

**

SEATED HIP BREADTH: Measurement taken with the subject sitting erect, the arms relaxed at the sides, forearms and hands extended forward horizontal to the floor, thighs supported by the sitting surface, and the long axis of the thighs parallel. Two flat surfaces are placed firmly against the thighs and the distance between the inner sides of the surfaces is measured.

*

SITTING HEIGHT: Vertical distance from sitting surface to top of the head.

SHOULDER BREADTH: Horizontal distance across maximum lateral protrusions of the right and left deltoid muscles measured with the subject sitting and the upper arms against the longitudinal axis of the body.

STATURE: Vertical distance from floor to top of the head with subject wearing stockings.

TOTAL ARM REACH: Measured with the subject's back against a wall, arms extended horizontal to the floor with no bend at the elbows, fingers extended, and the palms facing outward. Arm reach is the horizontal distance from the tip of the middle finger of one hand to the tip of the middle finger of the other hand.

WEIGHT: Weight of subject wearing a flight suit with empty pockets, underwear, and stockings.

* From Churchill et al. (1977)

** From Churchill et al. (1971)

APPENDIX B
ANTHROPOMETRIC MEASUREMENTS OF SUBJECTS

ANTHROPOMETRIC MEASUREMENTS OF SUBJECTS

SUBJECT #	STATURE	MASS	SITTING HEIGHT	SEATED EYE HEIGHT	FUNCTIONAL ARM REACH	TOTAL ARM REACH	UPPER BODY REACH	SITTING HEIGHT AND FUNCTIONAL ARM REACH	SITTING HEIGHT AND TOTAL ARM REACH	BIACROMIAL BREADTH	SHOULDER BREADTH	AVERAGE FORWARD BODY REACH	FUNCTIONAL LEG LENGTH	CROTCH HEIGHT	BUTTOCK TO HEEL LENGTH	BUTTOCK TO KNEE LENGTH	HIP BREADTH	HEAD CIRCUMFERENCE
1	153.4	55.4	83.8	71.7	68.1	159.5	126.5	151.9	243.3	33.4	42.7	120.2	88.3	71.0	95.6	55.4	33.5	58.2
2	152.5	50.1	80.0	70.9	67.4	152.5	123.3	147.4	232.5	30.1	34.9	114.4	90.9	73.7	95.5	53.1	36.3	54.1
3	155.9	60.9	86.4	75.6	68.0	149.5	126.4	154.4	235.9	31.8	40.8	122.3	90.7	72.4	92.0	52.9	37.5	53.8
4	146.9	48.0	80.5	69.7	71.8	146.3	122.3	152.3	226.8	29.5	35.8	108.7	86.7	68.7	90.6	51.1	33.7	53.5
5	162.5	68.1	90.8	80.1	72.3	163.5	128.8	163.1	254.3	38.9	47.4	124.2	99.6	75.4	95.7	54.1	36.7	56.5
6	161.1	83.8	87.2	76.9	76.1	163.5	129.5	163.3	250.7	38.3	45.5	124.1	97.1	77.6	103.8	58.7	38.4	59.1
7	156.4	59.5	83.6	72.8	72.0	162.6	129.7	155.6	246.2	35.6	39.6	107.9	96.8	72.3	97.8	54.3	38.5	56.7
8	158.3	65.7	83.9	73.2	79.3	160.2	123.5	163.2	244.1	34.3	41.0	117.0	98.0	76.2	103.4	58.5	38.9	55.3
9	182.3	84.5	98.8	88.7	82.1	181.7	147.0	180.9	280.5	38.3	49.2	138.4	110.2	84.8	111.8	61.3	39.4	58.3
10	184.1	86.4	90.8	79.5	83.6	194.7	146.8	174.4	285.5	41.3	47.6	145.7	116.2	93.7	125.1	67.3	38.1	57.8
11	183.9	84.3	96.1	85.8	81.0	185.7	148.4	177.1	281.8	40.3	45.9	140.0	111.7	93.0	112.9	62.3	38.5	56.4
13	186.3	81.8	98.7	86.4	82.2	188.8	149.5	180.9	287.5	40.2	49.7	145.9	111.8	89.2	112.9	65.4	37.0	60.2
14	186.5	87.2	99.6	88.2	81.0	190.0	150.2	180.6	289.6	41.4	51.5	137.7	116.6	89.8	114.7	63.0	42.4	58.3
15	189.0	82.3	96.0	85.5	87.7	193.8	145.8	183.7	289.8	40.2	47.5	142.5	116.5	96.1	122.8	67.4	39.0	57.4
16	189.5	96.8	96.0	85.7	87.1	190.8	153.7	183.1	286.8	34.9	50.6	142.6	120.5	93.4	123.5	67.9	41.5	57.7
17	192.5	110.5	97.3	86.3	89.5	196.5	155.1	186.8	293.8	43.3	50.7	147.5	119.8	96.0	126.5	67.7	42.3	58.6
18	192.4	78.1	100.6	91.5	84.2	195.1	156.0	184.8	295.7	38.2	46.0	136.0	116.5	93.4	124.1	63.4	38.7	58.4
19	194.5	101.4	102.8	87.3	92.1	198.0	159.8	194.9	300.8	42.4	51.7	134.8	116.0	92.2	122.5	66.0	41.5	58.1

NOTE: Linear measures are expressed in centimeters; mass in kilograms.

APPENDIX C
CRITICAL ANCILLARY CONTROLS

TH-55A

INSTRUMENT PANEL
altimeter set knob

CENTER CONSOLE
all

OH-6A

INSTRUMENT PANEL
pitot heat switch
radio magnetic indicator
altimeter
bypass air caution light
radios
attitude gyro

OVERHEAD
engine device lever
cabin heat and defog lever

ELECTRICAL CONSOLE
SCAV air switch
fuel pump switch
battery switch
inverter switch
generator switch

OH-58C

INSTRUMENT PANEL
radios
clock
warning panel
attitude indicator
altimeter
fuel boost switch
caution panel

OVERHEAD
heater switch
deice switch
pitot heater switch
defog switch

UH-1H

INSTRUMENT PANEL

altimeter
clock
attitude indicator
RMI

CENTER CONSOLE

UHF navigation radio
ADF control
signal distribution panel
radios
transponder
AC circuit breakers
engine panel
hydraulic panel

OVERHEAD

hydraulics control circuit breaker
generator and bus reset circuit breaker

UH-60A

INSTRUMENT PANEL

radar altimeter
barometric altimeter
master warning panel
vertical situation indicator
horizontal situation indicator
CIS mode selector
vertical/horizontal speed indicator mode selector
liquid water content indicator
blade de-ice control panel
infrared countermeasure control panel
engine ignition switch

OVERHEAD

No. 1 and No. 2 engine fuel selector lever
No. 1 and No. 2 engine off/fire T-handle
No. 1 and No. 2 power control lever
cockpit floodlight control
all of upper console

CENTER CONSOLE

all, including parking brake and battery/battery utility bus

CH-47C

INSTRUMENT PANEL

stick positioner
fire control handle
transmission oil temperature selector switch
transmission oil pressure selector switch
fire extinguisher agent switch

OVERHEAD

hydraulic electric power panel
fuel control panel
dome light panel
auxiliary power unit panel
flight control panel
hoist control panel

CENTER CONSOLE

all except UHF radio

CH-54B

INSTRUMENT PANEL

compass slave select switch
pilot's gyro select switch
flight direction indicator
altimeter

OVERHEAD

N1 levers
fuel shut-off levers
AC and DC circuit breaker panels
auxiliary circuit breaker panel
bypass door control
all overhead control panel switches

CENTER CONSOLE

transponder

AH-1S

INSTRUMENT PANEL

all

LEFT CONSOLE

all

RIGHT CONSOLE

all

AH-1S (copilot cockpit)

pilot override control

altimeter

gunner's control panel

TOW control panel switch

avionics

gunner electrical power switch

telescopic sight unit hand control

canopy removal arming/firing mechanism

T-42A

INSTRUMENT PANEL

static air source

landing gear control handle

mixture idle cutoff

SUBPANELS

navigation light switch

beacon light switch

fuel quantity switch

parking brake

transponder

circuit breaker panel

avionics circuit breaker panel

fuel boost pump switches

landing light switch

taxi light switch

PEDESTAL

landing lights

taxi switches

FLOOR

emergency landing gear control handle

U-8F

INSTRUMENT PANEL

attitude indicator
altimeter
clock
intercommunication box
RMI
windshield wiper control
windshield anti-ice switch
manifold pressure guage
radios
750 volt inverter circuit breaker

SUBPANELS

defrost air control handle
landing gear circuit breaker
flap motor circuit breaker
idle cutoff switches
start selector
left and right engine alternate air control
flap handle
magneto switches
primer button
start button
inverter switches
landing light switch
pitot heat switch
prop anti-ice switch
parking brake
master switch gang bar
cabin air switch
taxi lights switch
surface de-ice circuit breaker
anti-ice circuit breaker

CENTER PEDESTAL

all

U-21A

INSTRUMENT PANEL

annunciator panel
transponder
radios

SUBPANELS

- parking brake
- inverter switch
- master switch
- landing lights switch
- windshield anti-ice switches
- emergency landing gear control handle
- ignition and engine start switches
- heat switches
- engine ice vane control handles
- flap motor circuit breaker

FUEL MANAGEMENT PANEL

all

CONTROL PEDESTAL

all

C-12A

INSTRUMENT PANEL

- parking brake
- landing gear handle
- landing lights
- dump and pressurization switch

CONTROL PEDESTAL

- transponder
- flap handle
- control levers

OVERHEAD

- emergency lights
- flap motor circuit breaker
- No. 1 and No. 2 engine start switches
- windshield anti-ice switches
- No. 1 and No. 2 inverter switches
- avionics master power switch
- cabin temperature mode knob
- vent blower switch
- aft vent blower switch
- ignition and starting switches
- battery generator switches
- standby boost pump switches

OV-1D

INSTRUMENT PANEL

radios
BDHI course selector

CENTER INSTRUMENT PANEL

gear handle
emergency gear blow down handle

CONTROL PEDESTAL

control handles
emergency stores release

GLARESHIELD

fire handles

LOWER CONSOLE

all

OVERHEAD

engine no. 1 and engine no. 2 master switch
ignition buttons
generator power assist button
fuel pump switch
air conditioning control lever
generator switches
battery switches
inverter switch
weather control panel
engine crank case switch

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